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ORIGINAL PAPER

Genetic analysis of growth and wood variations in *Leucaena leucocephala* (Lam.) de Wit.

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Abstract: We selected 28 populations of *Leucaena leucocephala* from different geographical locations in the states of Andhra Pradesh, Tamil Nadu and Orissa of India on the basis of height and girth at breast height (GBH). We evaluated fiber length, optical density, wall thickness, vessel element length, vessel element diameter, specific gravity and lignin of these populations of *L. leucocephala* in different sites. Populations had significant variations for all growth, wood and paper parameters. Girth at breast height (GBH) and specific gravity were the most important parameters for heritability and genetic gain, respectively. The minimum heritability was reported for vessel element length and genetic gain for fiber length. The populations were grouped into six clusters, cluster II had maximum number of populations (14) and clusters IV and VI had one population each. GBH contributed maximum of 34.39 % towards total divergence followed by specific gravity (14.02%). An economic technique to produce quality seed by establishing seed orchards with genetically divergent parents was suggested. The hybridization among the populations selected from diverse clusters could produce greater heterosis needed for higher growth and suitable wood and paper manufacturing parameters.

Keywords: *Leucaena leucocephala*; wood parameters; heritability; genetic advance; seed orchards

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Introduction

L. leucocephala (Lam.) De Wit. belongs to the family Fabaceae and sub-family Mimosoideae, and is a native to Central America. In India, it was first reported to occur in Andaman and Nicobar Islands (Parkinson 1923), where it was grown as a hedge plant (Troup 1932). During 1931, the species was introduced for domestication by the Forest Research Institute, Dehradun, India to its demonstration plots (Kaul and Sharma 1981), which was later planted in all most all the provincial states of India. This species has now become a potential species for pulp and paper industry as an alternate pulp wood, because its wood produces satisfactory paper grade pulp and dissolves with favorable properties. The pulp is reported to be rich in cellulose content and low in silica as well as ash, and the pulp yield was reported to range between 50% and 52%. The fibers are shorter than the tracheids of pine wood, but almost equal to pulp of other hard wood species (Kulkarni 1980).

Wide variations are reported for wood quality parameters for different species, which depend upon variations exists in the dimensions of wood elements. The variability in anatomical characteristics has profound influence on properties of wood (Burley and Palmer 1979) including cell size, proportion and arrangements of different elements and specific gravity. In general, the pattern of variation in wood element in different tree species is not only found within a species but also observed significantly within a tree (Rao and Rao 1978). However, the variation for wood elements within a species is greatly affected by genotype, environment and the genotype×environmental interactions (Pande and Singh 2005).

The degree of variations and assessment of wood qualities for pulp and paper making properties in different tree species grown at varying environmental conditions was carried out by various workers (Singh and Naithani 1994). Though the selection of promising phenotypes based on morphological characteristics

from wide populations provides divergent genotypes and contributes in establishing diversified base material, genetic diversity for wood traits becomes an essential aspect particularly for a potential industrial wood like *L. leucocephala*, so that the degree of variation and its genetic control is understood. The analysis of genetic diversity becomes still more valuable in tree improvement programme owning to the long gestation period of trees (Zobel and Talbert 1984).

Though a preliminary study on intra and inter tree variations in physico-chemical and wood anatomical properties of *L. leucocephala* was carried out by Pande et al. (2008), a detailed study on various populations at different geographical locations of this species was required to screen promising genotype on the basis of growth and wood traits. Thus, our study was taken-up to analyze variations and genetic diversity for wood and growth traits among 28 populations growing at three provincial states of India. An attempt was made to ascertain the magnitude of genetic diversity among the populations of *L. leucocephala* using D^2 analysis.

Materials and methods

Growth and wood analysis

Four years old plantations of *L. leucocephala* in the states of Andhra Pradesh, Orissa and Tamil Nadu of India were surveyed and enumerated for height and girth at breast height (GBH) to select 28 populations of uniform age (Table 1). In each population, five phenotypically superior trees were selected to measure growth characteristics. Accordingly, the wood samples were collected from 28 sites spreader over to four districts of Andhra Pradesh *viz.* Krishna (9 sites), Prakasham (9 sites), Khamam (2 sites) and Guntur (5 sites), Tamil Nadu (2 sites) and Orissa (1 site) (Table 1).

Table 1. Source of different populations and site characteristics

S. No.	Code	Locality	Rainfall (mm)	Temp. (°C)	Soil type	Altitude (m)	Longitude	Latitude
1	ITC-BMC-163	Nandigama, Krishna, A.P	1000–1500	35–45	Black soil	116	80°14'720"	16°50'469"
2	ITC-BMC-182	Madhira, Krishna, A.P	1000–1500	35–45	Black soil	120	80°17'901"	16°45'100"
3	MPD-KRS	Krishna, A.P	1000–1500	35–45	Black cotton	117	80°13'729"	16°51'469"
4	ABT-KRS	Krishna, A.P	1000–1500	35–45	Black	124.2	80°17'927"	16°45'114"
5	MGL-KRS	Krishna, A.P	1000–1500	35–45	Black cotton	255.9	80°19'764"	16°48'743"
6	MPL-KRS	Krishna, A.P	1000–1500	35–45	Black cotton	81.3	79°33'052"	18°01'845"
7	KNCH-KRS	Krishna, A.P	1000–1500	35–45	Black cotton	114	80°21'139"	16°42'486"
8	ABT-KRS(BD)	Krishna, A.P	1000–1500	35–45	Black	80.1	80°17'908"	16°45'139"
9	LP-GUN	Guntur, A.P	800–1100	33–46	Black loamy	47.4	79°59'100"	16°08'667"
10	KVP-GUN	Guntur, A.P	800–1100	32–45	Black	52.5	80°05'735"	16°07'336"
11	STL-GUN	Guntur, A.P	800–1100	32–45	Black loamy	47.4	80°07'674"	16°14'514"
12	KMP-GUN	Guntur, A.P	1000–1500	35–45	Black loamy	66.6	80°05'675"	16°07'156"
13	MDH-GUN	Guntur, A.P	1000–1500	35–45	Black	24.3	80°04'804"	16°06'769"
14	GP-ONG	Prakasam, A.P	700–1100	33–46	Black loamy	30.6	80°01'002"	15°40'182"
15	EGP-ONG	Prakasam, A.P	700–1100	33–46	Black loamy	44.4	79°55'646"	15°36'098"
16	GDP-ONG	Prakasam, A.P	700–1100	33–46	Sandy loamy	59.4	79°56'314"	15°33'250"
17	KVP-ONG	Prakasam, A.P	700–1100	33–46	Black loamy	19.2	79°50'986"	15°34'130"
18	NGP-ONG	Prakasam, A.P	700–1100	33–46	Black loamy	54.9	80°01'044"	15°39'524"
19	CHK-ONG	Prakasam, A.P	1000–1500	35–45	Black	6.6	79°51'824"	15°36'007"
20	AKD-ONG	Prakasam, A.P	1000–1500	35–45	Black	26.7	80°02'157"	15°20'473"
21	NP-ONG	Prakasam, A.P	1000–1500	35–45	Black	9	79°56'316"	15°33'250"
22	TNG-ONG	Prakasam, A.P	1000–1500	35–45	Black loamy	55.5	80°04'663"	15°24'270"
23	CHD-KHM	Khammam, A.P.	1400–1500	40–45	Red Sandy Alluvial	54.3	80°58'942"	17°39'887"
24	KG-KHM- 4	Khammam, A.P.	1400–1500	40–45	Red Sandy	76.5	80°55'008"	17°38'801"
25	NG-KHM-5	Khammam, A.P	1400–1500	35-45	Red Sandy Alluvial	7.5	81°06'625"	17°38'084"
26	RMB-GNJ-1	Ganjam, Orissa	1000–1500	35 - 39	Clay loamy	25	85°05'412"	19°32'170"
27	TRY	Thiruchirappilly, TN.	-	-	-	108	78°41'073"	10°50'000"
28	K-4	Mokkumbu, Thiruchirappilly, TN	-	-	-	118	78°34'845"	10°52'817"

In this way, 140 discs of 5 cm thickness were collected at a uniform height of 1.37 m from 28 sites, and were brought to the Forest Research Institute, Dehradun for wood analysis. In the laboratory, each disc was considered for the anatomical analysis

individually adopting standard laboratory methods for preparation of macerations. Wooden blocks were fragmented into small chips and put in the test tube. These chips were macerated in 50% HNO_3 and a pinch of $KClO_3$. The macerated wood elements were thoroughly mixed and spread on a glass slide to take observations under compound microscope (Purkayastha et al. 1979). Measurements for fiber length, fiber diameter, wall thickness and vessel element length were taken from the macerated wood while tangential vessel element diameter were taken from cross sections. Under the microscope, 25 unbroken cells were sampled for the measurement for each parameter (Pande and Dhiman 2010).

The content of lignin was analyzed adopting by proximate analysis and specific gravity of each sample (block) was determined by the gravimetric method using single pan balance. The green volume of the blocks was measured by water displacement after blocks were fully soaked in water. Thereafter, samples were kept for drying in hot air oven at 103 ± 2°C till the constant weight and oven dry weight was recorded (Purkayastha et al. 1979). Basic density of wood sample was calculated as the ratio of oven dry weight and volume of saturated wood sample. Specific gravity was determined by using the following formula:

$$\rho_s = \frac{\rho_{wood}}{\rho_{water}} \tag{1}$$

Where, ρ_s is the specific gravity, ρ_{wood} is the Basic density of wood sample, and ρ_{water} is the density of water.

Statistic analysis

Variance

The statistical techniques as suggested by Sukhatame and Amble (1989) were applied for analysis of variance (ANOVA) as per following skeleton.

Source of Variation	Degree of freedom	Mean squares	Expectations of Mean Square
Clones	C-1	MS_C	$\delta^2 e + R\ \delta^2 c$
Replications	R-1	MS_R	$\delta^2 e + C\ \delta^2 R$
Residual	(R-1) (C-1)	MS_E	$\delta^2 e$
Total	(RC-1)		

Further analysis for genotypic and phenotypic components of variance from ANOVA was calculated as Burton (1952).

Genotypic variance:

$$\delta^2 g = \delta^2 e + R \cdot \delta^2 c - \frac{\delta^2 e}{r} \tag{2}$$

where, r is No. of replications, $\delta^2 c$ is the population mean squares, and $\delta^2 e$ is the error mean squares.

Phenotypic variance:

$$\delta^2 p = \delta^2 g + \delta^2 e \tag{3}$$

Genotypic coefficient of variance (GCV):

$$GCV = \frac{\sqrt{\delta^2 g}}{M} \times 100 \tag{4}$$

where, M is the mean.

Phenotypic coefficient of variance (PCV):

$$PCV = \frac{\sqrt{\delta^2 p}}{M} \times 100 \tag{5}$$

where, $\delta^2 p$ is phenotypic variance

Heritability

The broad sense heritability was calculated for different populations as suggested by Lush (1949).

$$h^2 = \frac{\delta^2 g}{\delta^2 p} \qquad 6)$$

where, h is broad sense heritability

Genetic advance

The genetic advance was calculated as described by Johnson et al. (1955).

$$G_s = K \cdot h^2 \sqrt{\delta^2 p} \tag{7}$$

where, G_s is genetic advance and K is the selection intensity, i.e. 2.06.

Genetic gain

The expected genetic gain as percentage of mean was calculated by Burton and Devane (1953).

$$G_g = \frac{G_s \times 100}{M} \tag{8}$$

where, G_g is the genetic gain and M is the mean.

Estimation of genetic divergence

Growth parameters *viz*. height and GBH, and wood variables *viz*. fiber length, wall thickness, vessel element length, vessel element diameter and specific gravity independently for 28 populations were subjected to D^2 statistic as described by Rao (1952)

and originally presented by Mahalanobis (1928) were considered to measure the group distance based on multiple characters.

Principal component of analysis

The principal component of analysis was applied to detect structure of the relationships between the variables (Thurstone 1931). The interpretation hierarchical factor analysis, as an alternative to traditional oblique rotational strategies was followed as Wherry (1984). The PCA enabled combining of two correlated variables into one factor, and extension of two-variable to multiple variables made computations more involved with expressing two or more variables by a single factor remains the same.

Results

Analysis of variance (ANOVA)

The general statics for 28 populations are presented for different wood and growth parameters (Table 2). The maximum coefficient of variation was reported for vessel element length (12.94%) followed by specific gravity (12.55%) and GBH (12.08 %). The minimum was reported for fiber length (4.47%), lignin (5.18%) and outer diameter (5.57%). The analysis of variance (ANOVA) depicts that all the parameters among the populations were highly significant at $p < 0.001$ (Table 3).

Table 2. Mean wood anatomical dimensions in µm (*n*=25), specific gravity and growth traits of different populations

Sites	Fibre length	Fibre diameter	Wall thickness	Vessel length	Vessel diameter	Specific gravity	Lignin (%)	Height (m)	GBH (cm)
ITC-BMC-163	1311	25.6	3.76	444.20	145.00	0.382	23.56	11.00	28.60
ITC-BMC-182	1295	25.6	3.69	477.40	156.60	0.360	23.07	11.20	27.80
MPD-KRS	1321	23.4	3.91	410.40	145.20	0.436	22.52	16.60	27.00
ABT-KRS	1312	22.4	4.52	382.60	139.80	0.460	21.79	18.20	25.40
MGL-KRS	1345	22.6	4.24	410.40	137.20	0.458	22.32	14.80	24.80
MPL-KRS	1252	21.4	3.80	390.80	106.00	0.480	22.04	15.00	22.60
KNCH-KRS	1291	23.2	4.41	453.40	132.20	0.460	21.89	14.00	24.40
ABT-KRS(BD)	1263	23.4	4.93	381.80	127.40	0.452	22.69	15.20	19.00
LP-GUN	1293	24.2	5.24	328.00	131.40	0.472	23.65	12.80	22.80
KVP-GUN	1355	23.0	4.69	384.40	134.60	0.450	25.35	14.60	24.60
STL-GUN	1339	24.2	5.22	382.20	138.80	0.484	25.28	15.60	21.80
KMP-GUN	1252	22.6	4.65	362.20	123.80	0.560	24.39	12.80	18.00
MDH-GUN	1231	22.8	4.58	342.00	128.20	0.546	23.62	12.40	17.80
GP-ONG	1348	22.8	4.31	399.00	127.80	0.496	21.40	13.20	25.00
EGP-ONG	1298	23.6	4.56	353.00	133.80	0.480	21.78	15.20	26.40
GDP-ONG	1261	25.4	4.65	381.40	147.80	0.426	22.32	14.00	25.40
KVP-ONG	1371	22.8	4.54	417.40	130.60	0.538	22.18	15.00	24.20
NGP-ONG	1314	23.0	4.27	402.20	138.60	0.484	20.65	14.80	23.60
CHK-ONG	1213	23.8	4.65	355.40	122.80	0.584	23.63	15.20	24.80
CHM-ONG	1295	24.4	5.09	343.00	137.40	0.584	23.22	14.80	25.00
NP-ONG	1329	22.8	5.09	402.20	125.40	0.640	22.90	13.40	22.00
TNG-ONG	1257	22.4	4.42	343.20	116.40	0.576	22.34	13.60	20.60
CHD-KHM	1356	22.8	4.84	389.20	136.60	0.420	21.81	14.00	21.00
KG-KHM	1310	25.8	4.65	432.80	154.00	0.374	23.34	11.60	33.80
AMR-KHM	1237	24.8	4.89	372.40	162.60	0.372	23.65	15.80	25.00
RMB-GNJ	1204	24.6	4.03	390.20	122.00	0.516	21.84	15.20	24.60
TRY	1328	22.8	4.81	400.20	144.60	0.604	22.31	15.80	34.10
K-4	1357	24.8	5.20	398.00	140.80	0.520	23.89	15.20	36.00
Mean	1294.57	23.59	5.56	390.34	135.26	0.486	22.84	14.32	24.87
SE	25.86	0.58	0.22	22.60	6.78	0.27	0.53	0.76	1.34
CV (%)	4.47	5.57	10.80	12.94	11.21	12.55	5.18	11.86	12.08

Table 3. Analysis of variance table (ANOVA) for different wood and growth traits of various populations of *Leucanea leucocephala*

Source of variation	Degree of freedom	Mean sum of squares								
		Fiber length	Fiber diameter	Wall thickness	Vessel length	Vessel diameter	Specific gravity	Lignin	Height	GBH
Populations	27	10309.89^{***}	6.49^{***}	0.97^{***}	6118.50^{***}	752.71^{***}	0.03^{***}	6.22^{***}	13.19^{***}	94.83^{***}
Replication	4	4214.14	5.54^{*}	0.02	1308.10	322.79	0.001	0.78	7.16^{*}	6.45
Error	108	3344.15	1.72	0.024	255.304	229.98	0.004	1.40	2.89	9.03

Genetic parameters

The variance (genetic, phenotypic and environmental), broad sense heritability, genetic advance and genetic gain were analyzed for both growth and wood anatomical traits (Table 4). The maximum GCV and PCV were calculated for GBH (16.66 and 20.58) and specific gravity (14.07 and 18.87), however, the maximum ECV was calculated for vessel element length (12.95). The data, therefore, depicts that GBH and specific gravity are two most important traits for genotypic and phenotypic coefficient of variation and indicates that considerable inter genotypic variation exists for further genetic improvement. The heritability expresses the degree to which a character is influenced by heredity compared to the environment. Estimation of broad sense heritability for various characters (Table 4) show low to moderate heritability, maximum being reported for GBH (0.66) and specific gravity (0.56). The minimum was however reported for vessel length (0.22) and fibre length (0.29). From Table 4, the highest genetic advance is observed for GBH (27.78) followed by specific gravity (21.62) and height (13.33).

Table 4. Details of different genetic parameters

Parameter	Genetic parameters								
	Fiber length	Fiber diameter	Wall thickness	Vessel length	Vessel diameter	Specific gravity	Lignin	Height	GBH
Genotypic coefficients of variation	2.88	4.14	8.39	6.84	7.56	14.07	4.30	10.02	16.66
Phenotypic coefficients of variation	5.34	6.94	13.67	14.64	13.52	18.87	6.73	15.53	20.58
Environmental coefficients of variation	4.47	5.57	10.80	12.95	11.21	12.55	5.18	11.86	12.08
Heritability (broad sense)	0.29	0.36	0.38	0.22	0.31	0.56	0.41	0.42	0.66
Genetic advance	41.70	1.20	0.48	25.70	11.78	0.11	1.29	1.91	6.91
Genetic gain	3.22	5.09	10.61	6.59	8.71	21.62	5.66	13.33	27.78

Genetic divergence

Data collected for wood variables and growth traits for 28 populations were subjected to Mahalanobis' D^2 analysis and Tocher' clustering to study genetic divergence. On the basis of Euclidean distances, 28 populations were grouped into six clusters (Table 5, Fig. 1). Cluster II had maximum populations (14) followed by cluster I (6), cluster III (4) and cluster V (2), and the rest of the clusters consisted two separate population (Table 5). The inter cluster D^2 values ranged from 13.24 (cluster I and III) to 48.82 (cluster I and V). Cluster V was found to be the most divergent cluster with maximum average D^2 values (35.14) followed by cluster I (25.87), whereas cluster II (20.41) and cluster III (20.54) had the minimum average D^2 values. The intra-cluster distances ranged from 0.00 (cluster IV and VI) to 12.05 (cluster II), which is an indicator of existence of substantial diversity among the populations.

The mean values for different characters were calculated by cluster wise (Table 6) to reveal considerable genetic difference among the populations (Table 6). Cluster II had the highest mean values fiber length (1,364.67 µm), outer diameter (24.00 µm) and vessel element length (409.53 µm). Similarly, cluster V had maximum values for vessel element diameter (142.70 µm), specific gravity (0.56), height (15.50 m) and GBH (35.05 cm). The minimum values however were recorded for cluster VI. Mean cluster values showed significant variations among the clusters. Cluster II showed higher fiber length, fiber diameter and vessel element values while cluster I and VI showed lowest fiber length. Cluster IV showed higher values of height while higher DBH was shown by cluster V. The dendrogram (Fig. 2) for 28 populations was prepared using Tocher Method to reveal similar pattern of information.

Table 5. Population composition of different clusters

Cluster No.	No. of populations	Populations			
I	**6**	12. KMP-GUN	13. MDH-GUN	22. TNG-ONG	19. CHK-ONG
		9. LP-GUN	8. ABT-KRS(BD)		
II	**14**	1. ITC-BMC-163	2. ITC-BMC-182	16. GDP-ONG	24. KG-KHM- 4
		25. NG-KHM-5	7. KNCH-KRS	15. EGP-ONG	5. MGL-KRS
		14. GP-ONG	18. NGP- ONG	3. MPD-KRS	23. CHD-KHM
		17. KVP-ONG	26. RMB-GNJ-1		
III	**4**	10. KVP-GUN	11. STL-GUN	20. AKD-ONG	21. NP-ONG
IV	**1**	4. ABT-KRS			
V	**2**	27. TRY	28. K-4		
VI	**1**	6. MPL-KRS			

Table 6. Cluster means of different parameters

Parameters	Fibre length	Fibre diameter	Wall thickness	Vessel length	Vessel diameter	Specific gravity	Lignin (%)	Height (m)	GBH (cm)
Cluster I	1252.10	23.20	4.75	352.10	125.00	0.53	23.31	13.67	20.50
Cluster II	1364.67	24.00	4.34	409.53	140.71	0.44	22.31	14.03	25.83
Cluster III	1330.00	23.60	5.02	377.95	134.05	0.54	24.19	14.60	23.40
Cluster IV	1312.40	22.40	4.52	382.60	139.80	0.46	21.79	18.20	25.40
Cluster V	1292.80	23.60	5.01	399.10	142.70	0.56	23.10	15.50	35.05
Cluster VI	1252.00	21.40	3.80	390.80	106.00	0.48	22.04	15.00	22.60

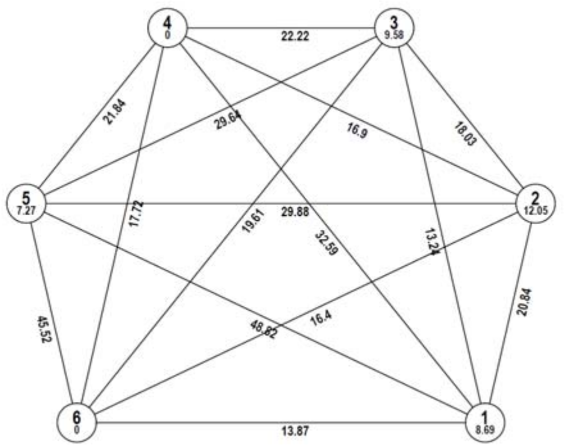

Fig. 1 Clusters of different populations

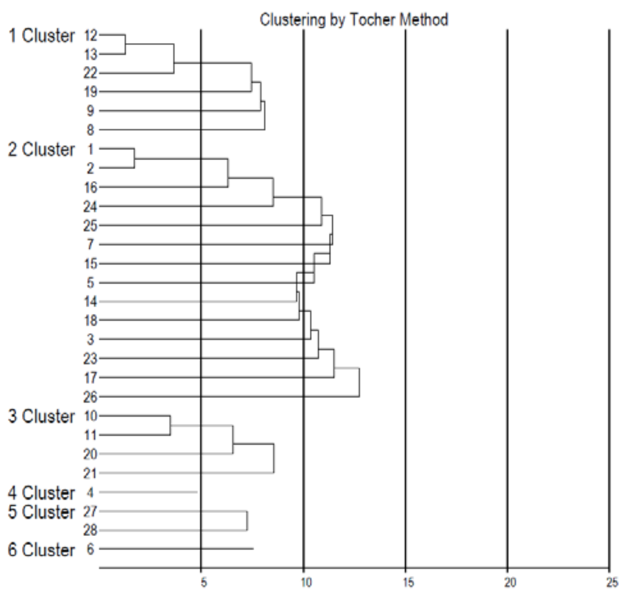

Fig. 2 Dendrogram developed through Tocher Method for different populations

Principal component analysis

The dispersion of different wood and growth parameters and relative contribution of each character towards genetic divergence was calculated in 28 populations and found highly significant (Table 7). Among the variables studies, the GBH was reported to be most significant character as it not only ranked first 130 times but also contributed maximum (34.39%) towards variability followed by specific gravity (14.02%), height (13.76%) and lignin (11.64%). The vessel element length, vessel element diameter and fiber diameter were found to be least important parameters to contribute just 3.70%, 3.70% and 3.90%, respectively towards total variability (Table 7). Different populations were accordingly been analyzed for PCA Score I and PCA Score II and plotted in 3D manner (Fig. 3).

Table 7. Details of dispersion in different wood and growth traits

Details of dispersion		
Source of variation	Degree of freedom	MSS
Populations	27	-6.8052E17***
Error	107	3.7751E05
Total	134	-1.3712E17
Contribution of different characters towards variability		
Source	Time ranked 1st	Contribution (%)
GBH	130	34.39
Specific gravity	53	14.02
Height	52	13.76
Lignin	44	11.64
Wall thickness	29	7.67
Fibre length	27	7.14
Fibre diameter	15	3.90
Vessel diameter	14	3.70
Vessel length	14	3.70

p *** =0.01 %

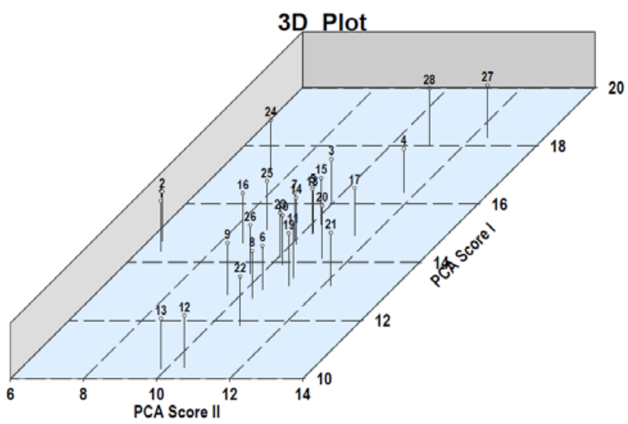

Fig. 3 Principal component analysis of different populations

Discussion

The genetic parameters are useful tools for predicting the amount of gain to be expected from different provenances/populations. The variation between the populations is commonly used as an estimate of total genetic variation and to calculate the degree of genetic control for a particular trait (Foster and Shaw 1988). The variation was found to be significant among different populations for the wood element dimensions like fiber length, fiber diameter, wall thickness vessel element length, vessel element diameter, specific gravity and lignin. Further, the variations were also significant for growth parameters viz. GBH and height among the populations (Table 3). Higher fiber length, wall thickness and lower lignin were observed in the populations of MGL-KRS, KNCH-KRS, GP-ONG, KVP-ONG and CHD-KHM suggested that there was ample scope for enforcing selection wherein inferior populations could be eliminated to improve the wood and growth traits genetically. The similar results for average specific gravity were recorded among the clones of *Populus* spp. (Chauhan et al. 1999) and *Eucalyptus tereticornis* Sm. (Rao et al. 2002). Significant differences among the clones for different tree species for average fiber length have reported by Phelps et al. (1982) and Rao et al. (2002). Clone to clone variations were studied in *Tectona grandis* for fiber dimensions (Rao and Shashikala 2003) and lignin content in *Pinus tadea* (Van Buijtenen et al. 1968).

Burton (1952) suggested that the genetic coefficient of variation together with heritability estimates could give appropriate estimate of genetic gain to be expected from selection. In our study, the environmental coefficients of variation (ECV) estimated for all the traits and were higher than their respective GCV, except for specific gravity to reveal significant influence of environment on the expression of different traits. High heritability in conjunction with high GCV was reported to be advantageous for practicing selection (Hanson et al. 1956). In the present findings the highest PCV estimates were recorded for GBH (20.58) and specific gravity (18.87) suggesting large amount of genetic variability for these traits and lower PCV values for fibre length (5.34), lignin (6.73) and fibre diameter (6.94) thereby indicating narrow variability for these traits. The pattern was studied by other workers also to report low value of GCV for height in *Bambusa pallida* (Singh 1993) and in *E. teriticornis* (Sundararaju et al. 1995).

Zobel and Talbert (1984) described the practical application of heritability and genetic advance in tree improvement. Genetic advance provides information about the extent of genetic gain which is possible to achieve through selection, while heritability indicates how much of the phenotypic variability is heritable. Xiang et al. (2003) showed that additional and significant gain can be achieved by keeping the entire non-additive component through vegetative propagation of the promising individual trees in full-sib families. Heritability estimates in broad sense could be reliable if accompanied by high genetic advance (Burton and Devane 1953). High heritability accompanied by high genetic advance for several growth parameters have earlier been reported by Solanki et al., (1984) in *Prosperis cineraria,* Dhillon et al., (1995) in *Dalbergia sissoo* and Kumar (2007) in *Gmelina arborea.* Among different traits, high heritability coupled with moderate advance and genetic gain were exhibited by GBH, specific gravity and height, which signifies the fact that these traits contain good amount of heritable additive genetic component that can be exploited for further selection and improvement of this species. Subramanian et al. (1995) also concluded that height, clear bole height, girth, diameter and basal area show moderate heritability and genetic advance in *Eucalyptus grandis*. In the present investigation, moderate heritability was associated with almost all the traits with low to high genetic advance, which indicates that additive gene effects play important role in *L. leucocephala*.

The genetic analysis carried out for wood anatomical parameters indicates that the differences between PCV and GCV for wall thickness, vessel element length, fibre length and vessel element diameter were less sensitive to environment. Moderate to high heritability (broad sense) could well be attributed to additive and non-additive gene effects. Koubaa et al. (1998) estimated the high heritability (0.41) for fibre length and concluded that the character in poplar hybrid clones appeared to be under strong genetic control. In *Populus* species, the genetic variation for specific gravity with moderate to strong heritability was calculated by Olson et al. (1985). The specific gravity was moderately strongly inherited and most traits were under the influence of additive gene action in *Tectona grandis* (Mandal and Chawhaan 2003). Specific gravity the most important wood property recorded heritability as 0.56 for *L. leucocephala*, which is within the reported range for heritability for most of the hardwoods.

In our study, 28 populations were clustered into six clusters based on wood and growth parameters and indicated that though the selected populations had sufficient genetic diversity, populations originated from the same geographical region had a tendency to come together in the same cluster. Divergence studies analyzes the degree of diversification and relative proportion of each component character to the total divergence, which measures the forces of differentiation at two levels *i.e*., at intra-cluster and inter cluster levels. In the investigation, intra-cluster distance ranged from 0.00 to 12.05 and inter-cluster from 13.24 to 48.82. Cluster II and V showed maximum inter-cluster diversity from all other clusters and the level of diversity was also substantially higher. Similar pattern of genetic diversity was observed in *Casuariana equsetifolia* by grouping 42 clones into 12 clusters (Kumar and Gurumurthi 2000). Singh (1993) explained that maximum heterosis occurs at an optimal or intermediate level of divergence. In forest tree crops, genetic divergence studies are also an effective tool for establishing seed orchards with diverse parents so that improved seed in most economic manner is harvested as diverse parents would have equal opportunities for hybridization and production of quality seeds (Kumar and Gurumurthi 2000). Hybridization between the populations selected from diverse clusters is expected to express higher heterosis and produce desirable recombinants and transgressive segregants.

The technique has effectively been applied in various forest tree species to find out genetically distinct populations in *Eucalyptus camaldulensis* and *Acacia nilotica* (Burley et al. 1971; Bagchi 1992).

Cluster II had the highest mean values for fibre length, outer diameter and vessel element length, and similarly cluster V had maximum values for vessel diameter, specific gravity, height and GBH. The populations assembled in this cluster were not only divergent but also had promising growth and wood parameters, which could easily be exploited for further improvement through hybridization involving populations of cluster II and V with any other cluster in various combinations. In hybridization, it is of utmost importance to select most divergent parents, so that maximum heterosis is obtained in the shortest possible time. It is also important to obtain immediate gain of high diversity by selecting these populations and establish in seed orchards.

The relative contribution of each character towards total genetic divergence was analyzed through principal component analysis (PCA) which demonstrated that GBH had contributed maximum toward variability. The minimum contribution towards genetic divergence was registered from vessel element length, vessel element diameter and fiber length. The parameters that have contributed substantially towards total divergence could well be used as desirable traits for selection. Though not much work was carried out on the PCA pattern in forest tree species, Manga and Sen (2000) reported that seedling height showed the highest contribution towards the genetic divergence followed by number of pinnules/pinna and inter-nodal length in *Prosopis cinereria*. Similarly, contribution of plant height towards genetic diversity has also been assessed in *Eucalyptus teriticornis* (Surendran and Chandrasekharan 1984).

Conclusion

The pattern of variability in *L. leucocephala* within and between the populations will not only have an impact on higher growth for production of more wood but will also influence the product of wood. It is known that the wood cost is one of the most important elements in the production of quality and economic pulp, and pulp cost is often the largest factor in paper cost. It is, therefore, important to understand and take advantages of variations for various growth and wood parameters to wood with the characteristics required for industries for different end uses. The exercise will ensure increase in its value in pulp and solid product industries. It is suggested that a shift in wood research to quality and inheritance is needed for assessing the degree and structure of genetic variations for each wood quality trait. Each of wood traits would play substantial role in contributing towards supply of quality wood, so that the end product could be produced in the most economic manner. A technique has been suggested in producing the quality seed by establishing the seed orchards with further selections among the most divergent populations so that maximum heterosis occurs. The genetic divergence therefore becomes an effective tool for establishing seed orchards with diverse parents so that improved seed in most economic manner is harvested as diverse parents would equally hybridize to produce quality seed, which will ultimately increase the productivity and supply of quality wood. The present study reveals that the Population No. 6 (MPL-KRS) originated from Krishna Distract of Andhra Pradesh could be utilized in various combinations in hybridization and establishment of seed orchards.

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